

CIÊNCIA E TECNOLOGIA NO BRASIL:

A CAPACITAÇÃO BRASILEIRA PARA A PESQUISA CIENTÍFICA E TECNOLÓGICA

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Physiological sciences (fisiologia)

Antonio C. Paiva*

1. Scope of this report

For the purposes of this report, the physiological sciences encompass the following disciplines: physiology, biochemistry, biophysics, pharmacology, parasitology, microbiology, immunology, and morphological sciences (anatomy, histology, and embryology), as well as cell biology, which pervades most of the other disciplines. Not included are the applications of physiological sciences in biotechnology, which are the subject of another report.

The survey of the state of the area in Brazil was made using the sources listed below.

- Annual reports and internal documents of the following granting agencies: Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, National Council for Scientific and Technological Development); Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes, Coordinating Agency for Advanced Training of High Level Personnel); Financiadora de Estudos e Projetos (Finep, Financing Agency for Studies and Projects); Fundação de Amparo à Pesquisa do Estado de São Paulo (Fapesp, São Paulo State Research Foundation).
- Documents produced by past analyses and evaluations, such as the last evaluation of the national system of science and technology made by CNPq (Seplan/CNPq, 1982) and the analysis of science and technology in the state of São Paulo made by Fapesp (1977), as well as the *third basic plan for the scientific and technological development*, issued by the federal government (Seplan, 1980), and documents of the Congress (Covas & Passoni, 1992).
- Institutional reports and published papers with evaluations of the scientific productivity and of the performance of the graduate study programs.
- Annals of the meetings of the scientific societies and interviews with individual investigators.

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The following individuals were interviewed or provided information used in this report:

- Renato Bailão Cordeiro, president of the Brazilian Society of Pharmacology and Experimental Therapeutics;
- A. Hasson-Volloch, president of the Brazilian Biophysical Society;
- L. Juliano, president of the Brazilian Biochemical Society;
- Eduardo Katchburian, professor of histology of the Escola Paulista de Medicina;
- J. D. Lopes, president of the Brazilian Society of Immunology;
- Maria Marques, president of the Brazilian Physiological Society;
- Isac Roitman, president of the Brazilian Society of Protozoology;
- Wanderley de Souza, president of the Brazilian Society of Electronic Microscopy;
- Luís R. Trabulsi, president of the Brazilian Society of Microbiology.

Data obtained from the different sources were sometimes fragmented, contradictory or outdated. It is particularly noteworthy the lack of dependable indicators of scientific activity in agencies such as Capes and CNPq, which are constantly collecting the information but are apparently incapable of processing and recording the large amount of data collected throughout the years. From the information provided by these agencies, some effort and common sense were necessary to arrive at plausible figures, which however cannot be considered exact and should be subjected to revision when more reliable and updated information are made available by these agencies responsible for the promotion of science and education in Brazil.

2. Where is research in physiological sciences performed in Brazil

Historically, Brazilian research in the physiological sciences began in a few medical schools and public health institutes of Rio de Janeiro and São Paulo. Public health institutes, such as the Instituto Oswaldo Cruz, in Rio, and the Instituto Butantã and Instituto Biológico, in São Paulo, were, in the past, prominent centers for biomedical research, including in the physiological sciences. However, because of their much greater dependence on political fluctuations, they lost

that position to the relatively more stable universities, which are responsible for the greater part of the scientific research being performed in the country today.

As for the private sector, it has played a very minor role in promoting research in the physiological sciences in Brazil, since the local pharmaceutical industry imports most of its products and processes, with very little research and development being conducted locally. This is also true of the state-owned biotechnology institutes which produce immunobiologicals and other health-related products.

One of the problems for the generation of a viable industrial research and development establishment has been the lack of interaction between academic investigators and the industries. This is due both to the lack of commitment of the latter to conduct research and development in this country, and to the resistance of the universities to this type of activity. A strict interpretation, by the universities, of full time dedication of their staff to teaching and research has hampered the use of their know-how outside the campus, as consultants and advisors to private companies. This attitude, however, appears to be reversing, and a promising trend in some universities is the installation of centers for research and development projects linking the academic expertise with the industrial sector. Notable examples of this trend, among others, are the University of Campinas Company for Technological Development (Codetec), the Federal University of Rio de Janeiro's Bio-Rio, and the technological annex to the Chemistry Institute of the University of São Paulo.

Another segment where research in physiological sciences should be increased is that of government public health institutes. These institutions have for a long time suffered from interference of spurious political influences and short-sighted policies that stifled their basic science departments. Fortunately, in recent years a clear trend to improve the scientific productivity has been evident in some of these institutes, such as the Fundação Instituto Oswaldo Cruz, in Rio de Janeiro, the Centro de Pesquisas René Rachou and the Fundação Ezequiel Dias, in Belo Horizonte, and the Instituto Butantã, in São Paulo. It is to be hoped that these institutions will have continuing success in their efforts to attain a more politically independent status, and to provide more attractive careers for their scientific staffs.

3. Funding

The main sources of support for basic scientific and technological development in Brazil are the federal agencies CNPq and Finep, of the Ministry of Science and Technology, and Capes, of the Ministry of Education. Several states also have agencies for science and technology support. However, only Fapesp, in the state of São Paulo, has played a major role in research funding. Another significant source of money for research is the Programa de Apoio à Ciência e Tecnologia (PADCT), with resources both from the World Bank and from the

Brazilian government. These resources are managed by Finep, CNPq and Capes.

Support given by these different sources to biological sciences in 1991 is shown in table 1. Although these numbers refer to all the biological sciences (including genetics, zoology, botany and ecology), figures related to physiological sciences may be approximated by considering that these sciences historically receive about 60% of the expenditures of the CNPq in the biological area.

Table 1
Support of biological sciences by different sources, 1991
(in US\$ millions)

Source	Fellowships	Projects	Total	%
CNPq	23.89	8.86	32.75	34.3
Finep	-	12.96	12.96	13.6
Capes	12.54	-	12.54	13.1
PADCT	-	6.74	6.74	7.0
Fapesp	1.74	23.29	25.03	26.2
Other state foundations	0.32	5.25	5.57	5.8
Total	38.49 (40.3%)	57.10 (59.7%)	95.59	100

It is noteworthy that Fapesp, which grants funds only to institutions in São Paulo state, appears as the most important source of money for research projects, contributing with 41% of the total amount granted in 1991. This is due, in part, to a sharp decrease in the federal support for science since 1989, reaching alarming proportions in 1991 and 1992, when CNPq practically withdrew its support to new grants, limiting its expenditures to fellowships and to grants contracted in the previous year. Table 2 shows that, except for the increase in the amount of CNPq support for research grants in 1992, research funding for projects by that agency has been decreasing since 1987. As for Finep, a trend for increasing its annual support for research projects in the period 1987-89 was sharply reversed since 1990. Thus, both federal agencies were greatly affected by the economic and political crises in the late 80's and early 90's. Unless this negative trend in support for science is quickly reversed, irreparable damage may be suffered by

research groups and institutions that took many years to consolidate and reach a reasonably productive stage.

Table 2
Federal grants for research projects: 1987-1991

Year	CNPq		Finep	
	Nº of projects	Amount (10 ⁶ US\$)	Nº of projects	Amount ^a (10 ⁶ US\$)
1987	709	5.0	111	13.3
1988	640	4.1	117	16.4
1989	517	2.7	166	19.3
1990	731	12.5	113	10.2
1991	922	^b	70	5.6

^a Excluding funds from PADCT.

^b Although around US\$20 million were granted to 922 projects in 1991, this money was not available that year nor in 1992, due to severe cuts in CNPq's budget execution.

It must also be pointed out that the low level of support to scientific research by federal agencies is undermined by the growing dispersion of available resources among numerous groups and individual researchers without rigid criteria regarding the quality and viability of projects. Another important shortcoming, which applies particularly to the CNPq, is the lack of adequate evaluation of the performance of the projects that receive support by the agency. These practices allow for the funding of numerous projects without merit, and the survival of groups that have presented mediocre or insignificant performances for years, at the expense of insufficient support for the most productive and highest performance research groups.

Those shortcomings do not apply to Fapesp, which, along years of serious and efficient administration, has developed an exemplary system of peer review and project evaluation that should be emulated by the federal agencies.

In the federal area, the resource fragmentation has been partially compensated by PADCT, which concentrates its resources in the most viable projects and productive groups, and is committed to play an important role in adequately supporting the most competent groups.

However, PADCT relies on funds from the federal government for all local expenditures of the projects, and this important part of the program is also marred by the lack of funding from the Brazilian government, which is not adequately complying with its obligations to the program.

The participation of the physiological sciences in PADCT is limited to areas included in one of the subprograms, namely biotechnology. In this program, emphasis is placed on supporting projects linking academic research in the universities to the development of products by the industry, but part of the resources is allocated to basic research. This has allowed for the survival of a few prominently productive groups which, in spite of the irregular supply of the funds for local expenditures (which, as already mentioned, depends on funds provided by the Brazilian government), have been favored by the possibility of purchasing abroad most needed equipment and supplies.

4. Work force

The number of active scientists in the physiological sciences may be appraised by some indicators available in the reports of the granting agencies and the respective scientific societies.

An indicator of people involved in any of the subareas is the number of ordinary (effective) members in the respective scientific societies. A list of these societies is given below, with the respective number of members (excluding student members and inactive members):

Subarea	Society	Number of members
Biophysics	Sociedade Brasileira de Biofísica	168
Biochemistry	Sociedade Brasileira de Bioquímica e Biologia Molecular	513
Immunology	Sociedade Brasileira de Imunologia	300
Microbiology	Sociedade Brasileira de Microbiologia Sociedade Brasileira de Virologia	468 59
Morphology	Sociedade Brasileira de Anatomia Sociedade Brasileira de Microscopia Eletrônica Sociedade Brasileira de Biologia Celular	600 481 72
Parasitology	Sociedade Brasileira de Protozoologia	220
Pharmacology	Sociedade Brasileira de Farmacologia e Terapêutica Experimental	428
Physiology	Sociedade Brasileira de Fisiologia	540

These numbers refer to the ordinary members at the end of 1992, with a small degree of uncertainty because some societies do not have an accurate number of actual full paying members. It must also be pointed out that, frequently,

scientists belong to more than one society, leading to an overestimation of the total number of researchers belonging to all societies.

Among the 3,849 members of the above listed societies, who supposedly are engaged to a greater or lesser degree in one of the physiological sciences, the more qualified are the holders of doctor's degrees. Table 3 shows that, in 1992, about 50% of the members of the physiological societies (1,946) held PhD degrees. Here again, the division between the disciplines is, in some cases, artificial, but the numbers give an approximate idea of the relative weight of their contribution to research in the physiological sciences in Brazil.

Table 3
Indicators of the size of the physiological sciences scientific community, 1992

Discipline	Holders of doctor's degree	Career fellowships	
		Pesquisador I	Pesquisador II
Biochemistry	436	62	106
Biophysics	88	12	24
Physiology	329	35	81
Pharmacology	244	34	71
Morphology	210	25	36
Immunology	193	32	43
Parasitology	235	27	52
Microbiology	211	28	66
Total	1,946	255	479

Sources: CNPq, Capes, and the Brazilian Societies of Biochemistry, Biophysics, Physiology, Pharmacology and Experimental Therapeutics, Anatomy, Electromicrography, Immunology, Chagas Disease (Trypanosoma and Leishmania) and Protozoology (malaria and other protozooses).

Another indicator, which reflects the number of the more productive investigators, is the number of holders of CNPq's career fellowships ("bolsas de pesquisador"). These are scientists classified by a peer committee into the categories of "Pesquisador I" (senior or independent researchers), and "Pesquisador II" (holding at least a doctor's degree and publishing regularly in refereed journals). The degree of selectivity of these two categories is given by the fact that, of the total of 1,946 scientists holding doctor's degrees, 734 (38%) have Pesquisador I or Pesquisador II fellowships (table 3).

Besides the Pesquisador I and II fellowships, CNPq also awards "special fellowships" (postdoctoral, regional development fellowships, associate investigators, fellowships for retired individuals continuing research, visiting investigators and recent-doctors). These categories, however, contribute little to the total number of investigators supported by CNPq fellowships, amounting, in 1992, to only 56 (7.1%) out of a total of 790 career fellowships granted to the physiological sciences.

As for the departments which conduct research in physiological sciences, an estimate of the active groups may be obtained from the data available from Capes regarding the accredited graduate courses in that area. Because of the structure of scientific organization and funding in Brazil, most research in any discipline is conducted in university departments that host graduate courses accredited by the Federal Education Council (Conselho Federal de Educação). Only these departments are able to obtain fellowships for graduate students, which constitute the major part of the scientific labor force in this country (postdoctoral fellows are a negligible part of that labor force). Therefore, these departments conduct practically all research done at a competitive level, and also receive most of the research grants available at federal and state funding agencies. Table 4 shows the number of accredited graduate courses in the different disciplines, at the end of 1991.

Table 4
Number of students and degrees awarded in December 1991

Disciplines	Number of students		Degrees awarded	
	Master	Doctor	Master	Doctor
Biochemistry	351	273	93	37
Biophysics	126	157	18	17
Physiology	133	54	36	12
Pharmacology	196	73	40	6
Morphology	56	83	11	14
Immunology	105	73	10	6
Parasitology	95	46	20	8
Microbiology	173	139	53	33
Total	1,235	898	281	133

Source: Capes.

5. Regional distribution

Research in the physiological sciences, as is also the case in other scientific areas, is heavily concentrated in the states of São Paulo (chiefly in São Paulo, Campinas and Ribeirão Preto), Rio de Janeiro and Minas Gerais (respectively in the cities of Rio de Janeiro and Belo Horizonte), although in certain disciplines there are active groups in other states, such as in the cities Curitiba, Porto Alegre and Florianópolis in the South, Recife and Fortaleza in the North-East, and Brasília in the Central region.

Concentration is the main characteristic pervading the regional distribution of the Brazilian scientific community doing research in the physiological sciences, since 40 (73%) of the 55 accredited courses are held in institutions in the South-East, with the remaining 27% distributed through the other four regions.

The regional imbalance is even more evident in the fact that, of the 30 courses accredited to award the highest degree (doctorate), 27 (90%) are in the South-East and only 10% are in the other four regions. The grades given to the graduate courses by Capes also reflect the regional imbalance. Of the courses evaluated in 1991, 90% of those of the South-East were graded A or B, whereas only 60% of those of the remaining regions received A or B.

The distortions in the regional distribution of scientific research groups have been the subject of a long-standing discussion, and some actions to overcome this problem have been taken by CNPq, which has carried out a program of "regional scientific development" for many years. Within this program, special criteria were adopted for granting aid to scientific projects coming from less developed regions. Although an objective evaluation of the results of this program is not available, the continuing stagnation of the scientific productivity in the best physiological sciences departments in these regions suggest that other types of action should be taken to improve the conditions and the efficiency of efforts carried out by local groups to conduct scientific research.

For many years, the current policy pursued by CNPq and Capes was to give priority to fellowships for students from less developed areas in Brazil to pursue their graduate studies abroad. This has resulted in a large number of PhD holders now found in the staffs of physiological sciences departments of North-Eastern universities. Thus, for example, 71% of the doctor's degrees of the staff in the Department of Biochemistry of the Federal University of Ceará were obtained abroad, and so were 90% of those in the Department of Biochemistry of the University of Pernambuco. In contrast, the percentage of the staff that obtained their doctor's degrees abroad is only 5% in the two most productive departments of biochemistry in the country, namely those of the University of São Paulo, and of the Biology Institute of the Federal University of Rio de Janeiro. Apparently, scientific productivity in these departments is inversely proportional to the proportion of their staffs holding doctor's degrees from foreign universities.

Experience has shown that, after an average of four years of graduate training abroad, students from less developed areas have serious problems to adapt to the working conditions of their home universities, where they do not find a favorable environment for scientific research (De Meis & Longo, 1990). This is also true, to a lesser degree, for individuals that took their PhDs in higher ranking universities in the South-Eastern region of the country.

Better results are obtained when graduate students follow a program in which at least part of their thesis work and courses are done in their local universities, with supervisors and visiting professors from more established graduate courses in the South-Eastern universities. An interesting experiment is the establishment of official co-operative programs between universities of different regions to allow students of less developed areas to conduct part of their graduate training in their local universities. Examples of such programs are those involving the Departments of Psychobiology and of Biochemistry of the Escola Paulista de Medicina, in São Paulo, and the Departments of Physiology and of Biochemistry of the Federal University of Rio Grande do Norte. Such programs have given good results in setting up new research groups where none existed before. However, they have also met some difficulties, and have shown that at least 10 years of intensive effort are needed for fostering groups with an autonomous scientific research program in less developed universities (Carlini, 1980; Moreira, 1991).

The most serious problem in the development of these new groups is the generation of scientific leadership, which is a long-term process. A strategy to circumvent this problem is importing scientific leadership from other universities. Highly successful examples of this strategy occurred in the Department of Biochemistry of the Federal University of Rio Grande do Sul and in the Department of Pharmacology of the University of Santa Catarina.

Another approach to generate qualified groups in less developed areas was carried out by the Laboratório de Imunopatologia Keijo Azami (Lika), in Recife, in which a massive investment from the Japan International Cooperation Agency (Jica) was used to create an institute where Japanese scientists worked with the local staff to set up modern equipped laboratories and research projects focusing on locally relevant problems. After a period in which the Japanese endeavored to create a self-sustained institute, Lika is now trying to proceed independently with its activities. An objective analysis of this interesting venture must await a few years of observation of its performance after becoming independent of the Japanese group.

6. Scientific productivity

Indicators of the amount of scientific productivity of the different disciplines in the physiological sciences, in Brazil, such as the ratio of 3.8 between the number of abstracts presented at annual meetings and the number of full papers pub-

lished in indexed journals, reflect the practice of fragmenting most research presented at the meetings so as to give each collaborator of the research the chance to present a poster.

When the total number of papers published in indexed journals published in Brazil and abroad (749) is divided by the number of holders of doctor's degrees (1,946, from table 3), an index of 0.4 paper per person per year is obtained.

Unfortunately, a qualitative analysis regarding scientific productivity in all the disciplines of the physiological sciences is not available. Only in biochemistry scientometric analyses have been effectively employed as an attempt to evaluate the qualitative performance of the area (see below).

7. Personnel training

Most of the qualified personnel which aggregates to the physiological sciences community each year comes from the accredited graduate courses. An idea of the annual output of this system is given by the number of students enrolled in these courses and the number of master's and doctor's degrees awarded in 1991. Table 4 shows that 281 new master's degrees were generated from a population of 1,235 registered students. This proportion of 23% is in line with the information provided by Capes that the average time to obtain a master's degree is about four years. For the doctor's degree, the output in 1991 was 133, out of a population of 898 students, indicating an average of more than six years for the awarding of that degree.

Graduate studies abroad are responsible for a smaller part of the degrees obtained by Brazilian scientists. Nevertheless, this segment has been stimulated in recent years, with a commitment of the federal agencies (Capes and CNPq) to maintain about 5 thousand fellows abroad, at an annual cost of US\$150 million. Theoretically, about 150 of these fellows should be getting back to Brazil with their degrees every year.

Table 5 shows that in the physiological sciences, in 1992, 28 students were working abroad for the MS and 92 for the PhD degree, with fellowships from CNPq and Capes. The only other agency giving significant, although much smaller, support for graduate studies abroad is Fapesp, which, between 1987 and 1991, granted 10 fellowships in the area of biological sciences for that purpose.

In the physiological sciences, the number of MS students abroad has drastically fallen down in the recent years, as the CNPq's advisory committees in these areas tend to abolish this kind of fellowship, recognizing that much better returns are obtained by investing in more mature students for training abroad. In this regard, the avowed priority of the agencies is the postdoctoral training, followed by the PhD fellowships. Nevertheless, when the number of postdoctoral fellowships granted by federal (CNPq, Capes) and state (Fapesp) agencies is compared to the number of doctor's degrees granted by Brazilian universities in a two-year period (average time of a postdoctoral fellowship), only about 25% of research-

ers holding these degrees are going abroad for postdoctoral work. Furthermore, the number of foreign PhD fellowships granted by federal agencies (CNPq and Capes) still exceeds that of postdoctoral fellowships abroad. In contrast, Fapesp clearly favors postdoctoral fellowships over PhD studies: in the period 1987-91, 80 foreign postdoctoral fellowships were granted by Fapesp, as compared to 10 fellowships for PhD abroad, in the biological sciences.

Table 5
CNPq fellowships for postgraduate training abroad, 1992

Discipline	Level			
	Specialization	MS	PhD	Postdoctoral
Biochemistry	2	2	22	11
Biophysics	2	0	5	7
Physiology	1	0	15	19
Pharmacology	3	0	19	12
Morphology	3	3	6	4
Immunology	3	10	12	13
Parasitology	1	7	8	6
Microbiology	2	6	5	4
Total	17	28	92	76

Sources: CNPq and Capes. (The numbers represent the fellowships granted by the two institutions in 1992.)

Mention should be made to the fact that an increasing number of fellowships granted by CNPq and Capes for graduate studies abroad, at PhD level, are "sandwich fellowships", in which the student is enrolled in a graduate course in a Brazilian university and pursues part of his thesis work overseas, working on a project which supposes a collaboration between his supervisor in Brazil and his host abroad. The "sandwich fellowship" program has the following advantages over the "full PhD" fellowships:

a) while studying abroad, the student maintains his ties with a Brazilian co-supervisor and fulfills part of his dissertation and course requirements in the Brazilian institution which will be responsible for awarding him his degree;

b) the requirement for a joint project between the Brazilian supervisor and a foreign colleague provides chances for international collaboration that may benefit the supervisor's research;

c) the student is kept abroad for a much shorter time than in a "full PhD" fellowship, with obvious economy of the scarce resources available.

A retrospective analysis of the scientific productivity (based on number of papers and impact of the journals) of age-matched groups of scientists that had obtained their PhDs abroad or in Brazil gave some interesting results (De Meis & Longo, 1990). The performance of scientists that obtained their degree in Brazil and never had formal training abroad was essentially the same as that of biochemists that had obtained their degrees in Brazil, and the publications produced in the course of their PhD work did not differ in number or impact. The authors conclude that, while postdoctoral training overseas is effective in improving the scientific productivity of Brazilian biochemists, no advantage is gained from sending them abroad to obtain their PhD. On the other hand, the average cost for a Brazilian student to obtain a PhD degree in biochemistry is about four times more expensive abroad than in Brazil.

When compared to developed countries, the scientific community in Brazil is very small, and the training of new personnel is well below the needs of the area. As an example, in 1985, there were 1.2 PhD and 3.0 MS degrees in the life sciences awarded per million inhabitants in Brazil (data from Capes), whereas in the USA there were 25 PhD and 40 MS degrees awarded per million inhabitants (National Science Foundation, 1987). Obviously, a vigorous scientific community in the physiological sciences cannot be attained in Brazil without a substantial increase in the number of qualified scientists produced by the graduate courses. However, several factors allow for restraining the growth of the system, some of which are discussed below.

Shortage of thesis supervisors

The number of qualified thesis supervisors in the accredited courses in physiological sciences is estimated to be around 600. Taking into account the total number of students shown in table 1, this indicates that, on the average, each supervisor has 2.0 MS students and 1.5 PhD student under his supervision. This suggests that the system is working at nearly full capacity, since the ideal average number of graduate students per supervisor is generally thought to be three.

This problem is aggravated by the Brazilian civil service rules that allow for full pay early retirement of university professors. This has two adverse results: the system loses professors that are in their fifties, at the height of their scientific productivity, and a large proportion of the universities' payroll is devoted to payment of inactive personnel. Some universities have adopted the policy of allowing their most qualified retired professors to be hired again, as full or associate professors. However, although they do not hold the same positions they had previously from retiring, this practice may be viewed, even when judiciously applied, as an incentive for early retirement of qualified personnel, as well as a

means to allow for the re-hiring of less qualified people, who will block positions needed for attracting competent younger scientists to the system.

In an attempt to alleviate this problem Capes has established a program to delay the retirement of scientists who are old enough to retire, but whose contributions to their highly rated graduate courses are considered important. In this program, significant fellowships are provided as long as the scientist does not retire and remains productive. Here, again, there is a danger of abuses, resulting in the occupancy, by scientists no longer productive, of positions that should be available to the new generation of scientists. An alternative that does not have this drawback is the "retired investigator" fellowship program that has been effective for several years in CNPq. This program allows for retired scientists still active and productive to continue their research and to contribute to the training of new scientists. These fellowships appear to be a better way of using the work of senior scientists, and should be made more attractive, by matching their values to those of the Capes program and by including some insurance of continuity of the support (with protection against inflation) as long as the performance of the awardee justifies it.

Shortage of experienced thesis supervisors is a difficult problem to overcome because the breeding of mature and competent scientists should include at least two years of postdoctoral work (preferably abroad), which means at least eight years of postgraduate training. A possible strategy to overcome this problem would be to import qualified scientists.

De Meis and Longo (1990) have estimated that bringing from abroad and maintaining a scientist with qualifications at least as good as those of the best thesis supervisors now available in this country would cost about the same as sending two graduate students overseas to get a PhD degree. According to these authors, with the amount spent by Capes and CNPq to sponsor 5,500 graduate students abroad (in all areas of knowledge) it would be possible to import 2,250 senior scientists. A major problem is to recruit scientists at the peak of their academic careers to settle in an underdeveloped country. However, this might be circumvented by selecting senior scientists approaching retirement, or seeking qualified personnel in countries with other problems, such as those of Eastern Europe. These possibilities are often discussed by granting agencies, but no serious effort has been made to bring a significant number of foreign scientists and to give them satisfactory conditions for carrying out research in their new environments.

Low efficiency of the graduate courses

The long time taken to train a graduate student is detrimental to the efficiency of the system: it takes about four years to produce an MS, and six to generate a PhD. This is due to several reasons, ranging from deficiencies in undergraduate training of many of the students (leading to longer periods of adaptation to the work at the graduate level), to the excessive emphasis in formal courses in

some graduate programs (delaying the initiation of thesis projects), and to delays in research work due to erratic support of the investigators by the granting agencies.

One short-term measure to decrease the time for producing a PhD is the elimination of the master's degree as a prerequisite for studies at the PhD level, which has become usual in some graduate programs. This prerequisite no longer applies, in some of the courses, for students that show a PhD potential. It is hoped that others will adopt a similar attitude, and regard the MS no longer as a necessary step for getting a PhD, but rather as a terminal degree for those students that do not qualify for a PhD.

However, the problem of lack of adequate undergraduate preparation of a good number of the students is not amenable to short-term relief, and will continue to impose the use, for correction of previous deficiencies, of some of the time that should be dedicated to graduate level work.

Shortage of good candidates for graduate studies

The supply of good candidates for the graduate courses is hindered by the lack of career incentives, since prospects for a job after finishing a graduate course is mostly limited to an academic career in the university, which offers few positions with low salaries. As a consequence, some of the brightest students are channeled to activities which are financially more attractive.

Incentives for research and development programs in the private sector, as mentioned above, would help to improve the career prospects and attract more qualified students to the graduate courses.

A program that has been successful for many years is the awarding of scientific initiation ("iniciação científica") fellowships, which allow early recruitment of undergraduate students for part-time participation in scientific research. This allows for the identification of individuals with scientific vocation that may be attracted to a scientific career, which would not otherwise occur. Furthermore, these students are far better prepared for entering graduate courses, and usually take a much shorter time to get their PhD degree. Thanks to its merits, the scientific initiation program held by CNPq has been strengthened in recent years, and it is hoped that this policy will continue.

8. Career opportunities

Despite the widespread need for qualified personnel in the physiological sciences in Brazilian universities, the demand for the new masters and doctors is discouraging, since the Brazilian civil service rules, particularly in the federal system (*regime jurídico único*), make it almost impossible to replace non-productive personnel with new people. Therefore, personnel turnover is very slow, and

the bringing up of new teaching and research posts is insufficient to stimulate a substantial growth in the number of active scientists in our universities.

It is to be expected that the *regime jurídico único* will be replaced by a special regime for the universities, allowing a more flexible policy in hiring new scientific personnel and replacing non-productive individuals.

One of the mechanisms to absorb newly-graduated doctors, while waiting for admission to a more permanent position, is the postdoctoral fellowship, which, in some countries, is an important source of manpower for scientific research. In Brazil, however, only a very small number of these fellowships are awarded. This is not due to shortage of such fellowships, which are easily available from federal and state granting agencies, but to a very small demand by the candidates.

Nevertheless, in spite of the reduced amount of posts available for new doctors, there is no significant unemployment because the small output of graduate courses is mostly absorbed by the academic system. Furthermore, postdoctoral fellowships for studies abroad are given high priority by granting agencies, and such fellowships are frequently awarded to the best graduates who are usually given positions in the universities' staff shortly after getting back to Brazil. As a result, postdoctoral fellows play a very minor role in leading the bulk of the research carried out by the most productive groups, which relies mostly on the work of graduate students.

Thus, though highly recommended from a training viewpoint, the policy of sending academic professionals abroad for postdoctoral work eventually deprives Brazilian laboratories from a better trained segment of researchers which, in other countries, is responsible for highly important contributions to the scientific productivity of the most active groups.

9. State of scientific research in the different disciplines

Biochemistry and molecular biology

Among the physiological sciences, biochemistry is the most active in Brazil, as far as number and productivity of scientists are concerned, and is also the discipline for which more performance indicators are available. In particular, a bibliometric analysis of the scientific production from the 19 most active groups (comprising 80-90% of Brazilian active biochemists) during the period 1970-85 (Meneghini & Fonseca, 1990; Meneghini, 1992) is an attempt to quantify research effort in this area. During that period, the 487 researchers published about 3 thousand papers in international journals (an average of 0.45 paper per year per person). These papers generated about 17 thousand citations in the period from 1983 to 1987, i.e., 5.7 citations per paper. These numbers do not lag behind those seen in first world countries, but the authors emphasize the hetero-

geneity of their sample, with important differences in productivity between groups and individuals, and a strong concentration of the most productive groups in the state of São Paulo and the city of Rio de Janeiro.

In spite of the very small size of the biochemical community in Brazil, with about one active biochemist for 300 thousand inhabitants, and although its productivity is still low when compared to more advanced countries, it has reached a certain level of maturity, and the ever increasing influence of molecular biology has brought added vigor to research in this area. A weak point is still the lack of more expensive equipment, such as mass spectrometers, NMR spectrometers and X-ray crystallography equipment (see below).

Biophysics

All federal universities in Brazil have departments of biophysics. However, serious research in this discipline is carried out in just a few of them, with emphasis on the Instituto de Biofísica Carlos Chagas of the Federal University of Rio de Janeiro. Due to its interdisciplinary nature, research in biophysics is pursued also in many departments of biochemistry and physiology, and it is hard to distinguish between these specialties when estimating their scientific productivity. In fact, most of the scientists surveyed for evaluating scientific productivity of biochemists belonged to the two most productive departments of biophysics in the country.

The main problem faced in this area is the lack of modern instrumentation, due to the high cost of equipment for physico-chemical and structural studies, such as those involving nuclear magnetic resonance, X-ray diffractometry, and mass spectrometry. High costs involved in acquiring and maintaining such equipment recommend a coordinated effort to be sponsored by federal and state scientific research agencies to build up national centers where more expensive equipment could be shared by scientists from different institutions. These centers are expected both to service facilities and to congregate groups of specialists working in projects involving intensive use of the equipment.

One such laboratory should be a mass spectrometry facility dedicated to biochemical and biophysical problems. There are several mass spectrometers located in many institutions in Brazil, but none of them is adapted and accessible for use by biologists. Therefore, a national laboratory for mass spectrometry should be settled, based in a pre-existing protein chemistry group which should be supported with equipment, personnel training and maintenance.

Another facility needed in a national center would be a nuclear magnetic resonance laboratory, where at least one large machine (for instance, 500 MHz) would be dedicated to biochemical and biophysical research.

A facility for X-ray crystallography should also be sponsored by a joint effort of the few laboratories where biological problems are studied relying on that technique. It is recommended that a station for protein crystallography be

included in the synchrotron which is now being settled by the National Laboratory for Synchrotron Light Project.

Physiology

Among the physiological sciences, physiology has the longest tradition of scientific research in Brazil, since the first physiological school came out of a laboratory set up in Rio de Janeiro in the 20's by Álvaro and Miguel Osório de Almeida. Disciples of these two pioneers irradiated to medical schools and other institutions in Rio de Janeiro and São Paulo, where they were later joined by the first Brazilian physiologists trained in the United States and Europe. The discipline grew slowly until the late 40's when the full-time regimen was created, first in the Faculty of Medicine of São Paulo, and later in the federal universities. In the 60's and 70's, with the creation and development of formal graduate courses and their strong support by federal agencies, the discipline grew at a faster pace. In the last decade, however, the area stagnated, which is evidenced by the slow growth in the scientific productivity of the most prominent departments, where a very productive generation of scientists trained in classical physiology has been slowly replaced by a new generation trained in more modern methods and concepts. It is desirable that a greater number of young physiologists get their post-doctoral training abroad in laboratories which will allow them to become familiar with new techniques and concepts of cell biology and molecular biology.

Pharmacology

As an offspring of physiology, pharmacology was set up in different institutions by researchers that came from the main physiological groups in the country, and since the 40's have been responsible for a growing scientific production in the area. However, in the last decade, pharmacology, as well as physiology, has been prone to a certain stagnation, which may also be attributed to a lack of renovation of the scientific leadership. Retiring researchers are not adequately replaced by a new generation of pharmacologists trained in the more modern methodologies, and the future of the discipline in Brazil depends on more intensive training of postdoctoral fellows in these methodologies.

Parasitology

The most productive research groups in parasitology are usually those involved with the study of *Trypanosomas* and *Leishmanias*. About 400 papers are presented in annual meetings on Chagas disease, representing the top research on the subject in the world. Conversely, the annual meetings of the Brazilian Society of Protozoology (which are held together with those on Chagas disease) have a much smaller number of contributions (59 in 1992). Themes as relevant as

malaria and amoebiasis are hardly the subject of good level research by basic parasitology groups.

The impressive development of *Trypanosoma* research in the last 20 years was, to a large extent, due to a special program (*projeto integrado*) funded by CNPq, which was responsible for coordinating efforts of different groups working in Chagas disease and for attracting new researchers to the area, with remarkable success.

Such "integrated projects" have been discontinued by CNPq, but the success of the Chagas disease group suggests that new programs on similar lines should be carried out for other areas such as malaria.

Microbiology

The evolution of microbiology in Brazil has taken place mostly in medical schools, where applied microbiology has been emphasized in detriment of other important topics of basic microbiology, such as the physiology and genetics of microorganisms. Traditional methodology still prevails in the area, in contrast to multidisciplinary approaches making use of the modern techniques of cell biology and molecular biology. As a result, scientific production is relatively low, when compared with most of the other physiological sciences. In particular, important specialties, like virology and food microbiology and toxicology, are neglected, and should be the object of concerted efforts, such as the promotion of special programs, which have been successful in improving the productivity of other areas (the protozoa research, for example, was greatly favored by the "integrated project" for the study of Chagas disease).

Immunology

Among the physiological sciences, immunology is one of the disciplines which has experienced the greatest progress at the international level in the last decade, with a great impact on the development of biotechnology. In Brazil, immunology has also been attracting growing interest, although the number of active groups of immunologists is still small. Among the 39 Brazilian universities, only 19 (48%) hold undergraduate programs in immunology, while among the 71 medical schools only 22 (31%) have courses in immunology. There are relatively few lines of research being pursued in a small number of groups, and there is little interaction and collaboration between these groups and with researchers in other disciplines, such as biochemists, pharmacologists, geneticists, and epidemiologists. These setbacks will only be overcome with an increase in the number of researchers in the area, depending mainly on an active support of personnel training by graduate courses in the more developed institutions in Brazil, which should be strengthened by bringing foreign visiting professors and by increasing postdoctoral training abroad.

Morphology

This area, which includes anatomy, histology, embryology and cell biology, has been traditionally dominated by the anatomists and histologists, who have played an important role in the teaching of medical students. There are about 2,500 scientists in the morphological sciences, distributed by around 80 medical schools and 90 universities and isolated institutions involved in undergraduate teaching in biological and health related areas. However, only a small part of this population works in academic research, namely that linked to accredited graduate courses. In 1991, it amounted to 130 docents holding doctor's degrees and had published 86 papers in international journals (0.66 paper/docent a year).

Progress in the scientific productivity of this area has been hampered by the contrast between the need to teach classical anatomy and histology to medical and biological students and the modern developments in cell biology. Most researchers in this area have been slow to adopt new concepts and methodologies to their research, resulting in a poor performance reflected in the low grades assigned by Capes' peer review committees to graduate courses in this area, including those of universities which rate best in other areas.

There is a coordinated program to improve the working conditions in this area — the Programa Setorial de Microscopia Eletrônica, sponsored by Finep — which gives support to several electronic microscopy laboratories. Similar coordinated efforts to introduce and support modern concepts and techniques in the morphological departments of Brazilian universities should be promoted.

10. Conclusions and recommendations

Availability of data on scientific performance

Data gathered for this report from different sources are sometimes fragmented, contradictory or outdated, and some effort and common sense were necessary to arrive at plausible figures which, however, cannot be considered exact and should be subjected to revision when more reliable and updated data are made available by the agencies responsible for fostering science and education in Brazil. These agencies (Capes, CNPq, and Finep), which have been collecting data about the scientific community in Brazil for years, should make an effort to recover these data for useful processing, and make them available as a basis for the evaluation of the performance of the different areas.

Interaction between basic science and technology

The industries depend very little on the universities for their know-how and do not hire a significant number of masters and doctors formed in graduate schools. This situation might be improved if changes are introduced in the indus-

trial policy of the Government favoring investments by the private sector in science and technology leading to a significant research and development effort in Brazil.

Recent trends to improve scientific productivity in federal and state biotechnological institutes should also be continued, and these institutions should attain a more politically independent status and provide more attractive careers for their scientific staffs.

Funding

Total public investment of 0.7% of the GNP in science and technology might be appropriate if funds were adequately managed and if they were supplemented by significant contributions from the private sector.

The main federal agencies for science funding — Finep and CNPq — were severely affected by the recent economic and political crisis. Unless this negative trend is quickly reversed, research groups and institutions are bound to suffer irreparable damage.

PADCT may play an important role, after the recognition that basic science must also be supported, avoiding pulverization of available resources by concentrating its support in the most viable projects and productive groups. However, it is absolutely necessary that the Brazilian government meet its obligations to this program, since its contribution is essential to support the local expenditures of the projects.

As a result of a chronic lack of funds, or of an inefficient planning in the distribution of available funds, important investments in more expensive equipment have been neglected. Prominent investigators in the different disciplines should be consulted about bottlenecks in their areas due to lack of modern instrumentation, and cooperative projects should be encouraged to acquire high-cost equipment for common use. National centers should be supported, where more expensive equipment could be shared by scientists from different institutions. These centers should not restrict to function as service facilities, but rather gather groups of specialists working in projects involving intense use of the equipment. Important examples of these laboratories that are much needed for the progress of physiological science research would be a mass spectrometry facility, and a nuclear magnetic resonance laboratory dedicated to biochemical and biophysical research. A facility for X-ray crystallography should also be set up, and a station for protein crystallography be included in the synchrotron now built by the National Laboratory for Synchrotron Light Project.

"Integrated projects" funded by CNPq, highly successful in the case of the Chagas disease group, should be sorted out for other areas, such as malaria and the application of modern techniques in morphology, physiology and pharmacology.

Regional imbalances

Distortions in the regional distribution of scientific research groups are not amenable to simple solutions tried in the past, such as CNPq's "regional scientific development" program, and other types of action should be taken to improve the conditions and the efficiency of efforts made by local groups to conduct scientific research. A growing cooperation between graduate courses of the less and more developed regions should be fostered, replacing the expensive policy of sending abroad students from less developed areas to get a PhD degree. It would be interesting to set up official cooperative programs between universities of different regions to allow students of less developed areas to have part of their graduate training in their local universities.

Personnel training

To improve the efficiency of graduate training in the physiological sciences, the shortage of qualified thesis supervisors should be compensated by an active policy of hiring scientists abroad, and by intensifying "sandwich fellowship" programs sponsored by Capes and CNPq, which prove to be a better alternative than supporting "full PhD" fellowships abroad.

Career opportunities

In spite of the small number of posts available for new doctors, there is no significant unemployment in the area as a result of small output of graduate courses. Together with efforts to increase this output, postdoctoral fellowships should be fostered as a mechanism for temporarily absorbing newly graduated doctors into active research groups.

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